CAIs IN ORDINARY AND ENSTATITE CHONDRITES.

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Introduction: Calcium-rich, Aluminum-rich Inclusions (CAIs) are the first-formed solids in the Solar System and recorded events in the early Solar System. They are abundant in carbonaceous chondrites (CC), which are thought to have accreted in the outer Solar System, and are also found in non-carbonaceous (NC) chondrites (ordinary and enstatite), which formed in the inner Solar System. Many hundreds of CC CAIs have been well-studied and classified based on size distributions, texture, mineralogy, petrography, and isotopic composition [1,2]. In contrast, only about 250 NC CAIs have been found, and most have not been characterized based on isotopic compositions [3–13]. Here, we report preliminary results of a comprehensive study of NC CAIs with the over-arching goal of understanding their relationship to CC CAIs. The first step was to find and characterize the physiochemical traits of NC CAIs. In the future we plan to determine the isotopic compositions of a subset of these CAIs.

Methods: We studied OC and EC thin and thick sections from UCLA, the Meteorite Working Group (MWG), and NWA 5206 (L3.05); 13 EH3 and EL3 meteorites and 45 OC meteorites sampling L, LL, H and ranging in petrologic type from 3.00 to 3.8. Using the Tescan Vega-3 XMU Scanning Electron Micropscope (SEM) at UCLA, we x-ray mapped the 58 sections with <10 µm per pixel resolution, located CAI candidates using the Al map or Mg-Ca-Al composite maps, then revealed CAIs as small as ~4 µm in diameter, using an energy dispersive spectrometer (EDS) upon locating minerals such as spinel, hibonite, Al-Ti-diopside, anorthite, melilite, and perovskite. We used the open-source software *ImageJ* to determine the size of all meteorite sections and CAIs. Due to the difficulty of outlining the exact CAI shape, we find a CAI area measurement systematic error of about 10%. We performed precise analysis via UCLA's JEOL JXA-8200 electron microprobe on a subset of CAIs.

Results: In ~8,000 mm^2 of NC meteorites, we found 75 CAIs in 45 OC sections (~6,600 mm^2) and 56 CAIs in 13 EC sections (~1,400 mm^2) for a total of 131 CAIs discovered so far.

CAI sizes. In apparent diameter, OC CAIs have an average size of is 52 µm, a median size of 32 µm, and they range from 4 µm to 275 µm. In apparent diameter, EC CAIs have an average size of 44 µm, a median size of 39 µm, and they range from 8 µm to 119 µm.

CAI abundances. In OCs, CAIs comprise 0.005 vol.% while in ECs, CAIs comprise 0.008 vol.%. We find that the abundance of CAIs in low petrologic type OCs (in 3.05s, CAIs compose 0.001 vol.%) is much less than in higher petrologic types (in 3.4s, CAIs compose 0.01 vol.%).

CAI types. We define 8 CAI groups based on mineralogy (from most to least abundant): spinel-rich, hercynite-rich, alteration-rich, hibonite-bearing, hibonite-rich, AOA-like, melilite-rich (only 5 CAIs), and corundum bearing (only 1 CAI). We also found some CAIs that are simply a grain of pure spinel or hibonite. We also found many Al-rich chondrules that commonly include spinel.

Mineralogy. We observed a few overall trends in mineralogy. First, we find an increasing presence of FeO-rich (20 wt.%), ZnO-bearing (~2 wt.%) spinel in CAIs from higher petrologic type OCs. Common alteration phases include sodalite, nepheline, and ilmenite; phyllosilicates are uncommon. The Al-Ti-diopside typically has ~0-4 wt.% TiO_2. Melilite is typically Al-rich, with $Åk_{<20}$. Hibonite is typically composed of Al_2O_3 > 80 wt.%, TiO_2 1-4 wt.%, and some FeO < 1 wt.%.

Discussion: Because CAIs from OC and ECs are rare and small, they have not been extensively studied. Prior studies suggest that NC meteorites have <0.1 vol.% of CAIs [2]; [10] finds 68 EC CAIs comprising 0.005 vol.% with 47±35 µm in apparent diameter and [9,10] finds that OC CAIs are 82±52 µm in apparent diameter. We observe similar distributions and sizes of CAIs in OC and ECs. In contrast to [10], we find that petrologic type affects CAI distributions, suggesting perhaps that higher petrologic type chondrite parent bodies formed earlier than 3.00 to 3.2 OCs. Our preliminary data affirms that NC and CCs have distinct populations of CAIs, in a physiochemical sense. CC CAIs comprise ~0.5-5 vol.%, ranging in size from µm to cm, and are typically composed of minerals spinel±melilite±diopside±anorthite±hibonite±grossite [1,2]. On the other hand, NC CAIs are 100 to 1000 times less abundant, are typically small with none larger than a few hundred µm, and are predominantly composed of spinel, hibonite, diopside, and alteration minerals.

References: [1] MacPherson G. J. (2013) Treatise on Geochemistry, 2nd edition, 139. [2] Scott E. R. D. and Krot A. N. (2013) Treatise on Geochemistry, 2nd edition, 65. [3] Bischoff A. and Keil K. (1983) Nature 303:588. [4] Russell S. S. et al. (2016) LPS 47, Abstract #1989. [5] Russell S. S. et al. (1996) Science 273:757 (1996). [6] McKeegan K. D. et al. (1998) Science 280:414 (1998). [7] Guan Y. et al (2000) Science 289:1330. [8] Fagan T. J. et al. (2000) MAPS 35:771. [9] Kimura M. et al. (2002) MAPS 37:1417. [10] Lin Y. et al. (2006) MAPS 41:67. [11] Ebert S. et al. (2018) EPSL 498:257. [12] Haugbølle T. et al. (2019) AJ 158:55. [13] Ebert S. et al. (2020) GCA 282:98. [14] Kleine T. et al. (2020) Space Science Reviews 216:55.